

## WAITING IN PIGEONS: THE EFFECTS OF DAILY INTERCALATION ON TEMPORAL DISCRIMINATION

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Pigeons trained on cyclic-interval schedules adjust their postfood pause from interval to interval within each experimental session. But on regular fixed-interval schedules, many sessions at a given parameter value are usually necessary before the typical fixed-interval "scallop" appears. In the first case, temporal control appears to act from one interfood interval to the next; in the second, it appears to act over hundreds of interfood intervals. The present experiments look at the intermediate case: daily variation in schedule parameters. In Experiments 1 and 2 we show that pauses proportional to interfood interval develop on short-valued response-initiated-delay schedules when parameters are changed daily, that additional experience under this regimen leads to little further improvement, and that pauses usually change as soon as the schedule parameter is changed. Experiment 3 demonstrates identical waiting behavior on fixed-interval and response-initiated-delay schedules when the food delays are short (<20 s) and conditions are changed daily. In Experiment 4 we show that daily intercalation prevents temporal control when interfood intervals are longer (25 to 60 s). The results of Experiment 5 suggest that downshifts in interfood interval produce more rapid waiting-time adjustments than upshifts. These and other results suggest that the effects of short interfood intervals seem to be more persistent than those of long intervals.

*Key words:* linear waiting, timing, fixed-interval schedules, response-initiated delay schedules, key peck, pigeons

One of the most reliable aspects of performance on any reinforcement schedule is the postreinforcement pausing observed when reinforcers are delivered at regular time intervals. Independent of any response–reinforcer contingency, birds and mammals (including humans, under some conditions) learn to postpone food-related responses after each food delivery for a time proportional to the typical interfood interval (temporal control: Chung & Neuringer, 1967; Ferster & Skinner, 1957; Richelle & Lejeune, 1980; Schneider, 1969).

The simplest and best studied periodic schedule is the fixed interval (FI), in which the first response a fixed time, *I*, after the last food presentation produces food. In the first systematic study of FI schedules, Ferster and

Skinner (1957) found postfood pausing within the first session, even with *I* values up to 8 min (p. 137 ff.). Nevertheless, most workers accept that many tens of sessions are necessary before the FI cumulative record appears stable, which implies that temporal control develops slowly (e.g., Catania & Reynolds, 1968; Cumming & Schoenfeld, 1958). There are other contrary data, however. For example, when the interfood interval (IFI) varies periodically within a session (cyclic-interval schedules: Higa, Wynne, & Staddon, 1991; Innis, 1981; Innis & Staddon, 1971), postfood pause tracks the cyclically varying sequence of interfood intervals. Under some conditions, therefore, temporal control appears to develop rapidly.

This paper is one of a series studying the dynamics of the adaptation to temporal schedules by pigeons. Our focus here is not just on the steady-state relationship between IFI and postreinforcement pausing, but on the way this adaptive pattern develops with experience.

In experiments with pigeons on a noncyclic schedule, Wynne and Staddon (1988) showed that under a variety of conditions, the length of time pigeons wait before the first key peck is a constant proportion of the IFI. These experiments used a modified FI schedule we have called a response-initiated-delay (RID) schedule. On our RID schedules, each trial begins with red illumination of the single response

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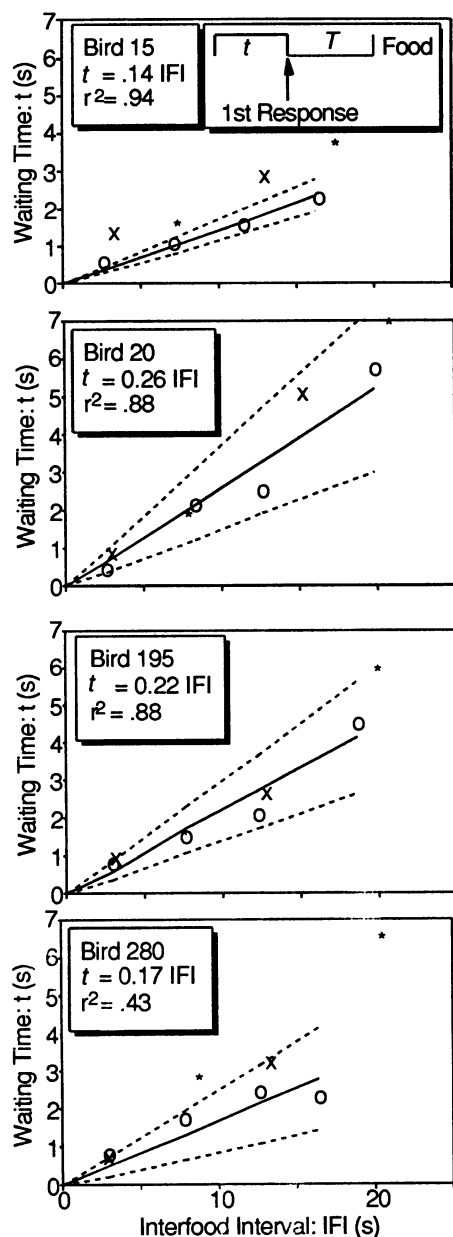


Fig. 1. Condition median waiting times against median interfood intervals for each bird in Experiment 1 and in Wynne and Staddon (1988). Each panel includes the regression line through the origin with 95% confidence interval and the regression equation parameters. Solid lines: regression fits through the origin. Dashed lines: 95% confidence interval. Circles: Experiment 1. Crosses: Wynne and Staddon (1988, Experiment 1). Asterisks: Wynne and Staddon (1988, Experiment 2). Insets: regression parameters, and one cycle of the response-initiated-delay (RID) schedule (top frame only).

key. The pigeon's first peck turns the key green. The time to this first peck is termed waiting time ( $t$ ), and is a dependent variable (entirely under the subject's control). After the first peck, the key remains green for a further time,  $T$  (the food delay), before food is delivered.  $T$  is determined by the experimental control program. The next trial follows without a break. One cycle of the RID procedure is inset in Figure 1.

Wynne and Staddon (1988) looked at versions of the RID procedure in which food delay,  $T$ , was either constant or depended in two different ways on the preceding waiting time,  $t$ . They found that despite the fact that schedule parameters were changed frequently (daily, in Experiment 2), and no matter how  $T$  was programmed, obtained median values of  $t$  were the same linear function of the obtained value of  $T$  (or the interfood interval,  $I$ , because  $I = T + t$ ):

$$t = AI + B, \quad (1)$$

where  $A$  was approximately .25 and  $I$  was less than 20 s. The intercept,  $B$ , was close to zero. Wynne and Staddon termed this result obligatory *linear waiting*.

The experiments reported by Wynne and Staddon (1988) and Higa et al. (1991) have shown that under a variety of conditions temporal control appears to develop extremely rapidly; however, a long history of research on temporal schedules has assumed that temporal control can only develop slowly. The aim of this paper is to identify the conditions under which adaptation to interfood intervals is rapid, and those conditions in which numerous interfood intervals are necessary before stable patterns of responding controlled by the IFI appear. We find that the precise nature of the schedule under which subjects are tested is unimportant; a more important factor determining the rapidity of adaptation to IFIs is the absolute length of the IFI. Short IFIs are much more effective at controlling waiting times than are long ones.

In Experiments 1 and 2, we study how practice affects the relation between waiting time and interfood interval and present a micro-analysis of this relationship. Experiment 3 compares two schedule types, FI and RID, that have been reported to produce different relationships between waiting time and IFI

when studied in blocks of identical sessions (Manabe, 1990). We compare the two types when parameters and schedule types are changed randomly from day to day. We explored the possibility that pigeons learn long and short IFIs differently in Experiments 4 and 5. In Experiment 4 longer IFIs were presented with daily intercalation of schedule values; similar longer IFIs were presented in blocks in Experiment 5.

### EXPERIMENT 1: METASTABILITY ON DAILY INTERCALATED RID SCHEDULES: DOES PERFORMANCE IMPROVE?

Manabe (1990) noted a small, not-quite-statistically-significant increase in the pause fraction (Parameter  $A$  in Equation 1) between the same subjects in Experiments 1 and 2 of Wynne and Staddon (1988). He suggested that the short postreinforcement pauses found in those studies could be due to the small number of sessions conducted at each parameter value, and that the small improvement in temporal control between the first and second experiments represents a real improvement with added experience. Changes in performance with extended training would be expected if the underlying process of adaptation to IFIs is indeed slow. This kind of improvement following an intervening treatment is known as *metastability*, and should be distinguished from a change in performance across a number of consecutive sessions under the same conditions. Metastability has been found on spaced-responding schedules (Staddon, 1965). In this experiment, we looked at the subjects from the study of Wynne and Staddon (1988) after additional experience on temporal schedules to see if the small improvement between Experiments 1 and 2 in the earlier study was maintained.

### METHOD

#### *Subjects*

The same 4 homing pigeons (*Columba livia*) served as in the previous studies (Wynne & Staddon, 1988). In the interim, they received about 6 months of exposure to a variety of RID schedules. They continued to be held at 80% of their free-feeding weights.

#### *Apparatus*

Subjects were studied in a cubic conditioning chamber (33 cm on a side) at the Ruhr-Universität, Bochum. A single response key (2.5 cm diameter) that could be transilluminated with red or green light was situated in the center of the back panel, 21 cm above the floor. The food-hopper opening (2 cm diameter) was 7 cm above the floor and projected 3 cm in front of the center of the back wall. A houselight was illuminated throughout the experiment. There was no hopper light. The experiment was controlled by a Commodore® microcomputer, which also recorded the times of all experimental events. Data were transferred to a larger computer for analysis at the end of each session. In all data analyses, in this experiment and the others, the first cycle in each session was discarded.

#### *Procedure*

At the beginning of each cycle, the key was illuminated red (see diagram in Figure 1). It remained red until the pigeon's first response (waiting time,  $t$ ). After the first peck, the red keylight was replaced by green. The key remained green for a delay time,  $T$ , set by the experimenter for each session, before 2-s access to mixed grains. Responses during green were recorded but had no scheduled consequences. Each session consisted of 100 cycles of the same  $T$  value with no intertrial interval. The houselight remained on throughout each session. Because the birds had extensive histories on this kind of study, no shaping or other pretraining was used. The subjects were exposed to daily sessions consisting of one of four  $T$  values (2, 6, 10, and 14 s), presented in random order three times each (twice for the 10-s value for Bird 15), for a total of 12 sessions (11 for Bird 15).

### RESULTS AND DISCUSSION

Figure 1 shows the median times to the first postfood peck (waiting time,  $t$ ) for each bird as a function of the interfood interval,  $I$ . Regression lines through the origin (Parameter  $B$  in Equation 1 set to zero) for each bird with 95% confidence intervals are also shown (data points that lie outside the area defined by the confidence intervals deviate significantly from the line). These regression lines were calcu-

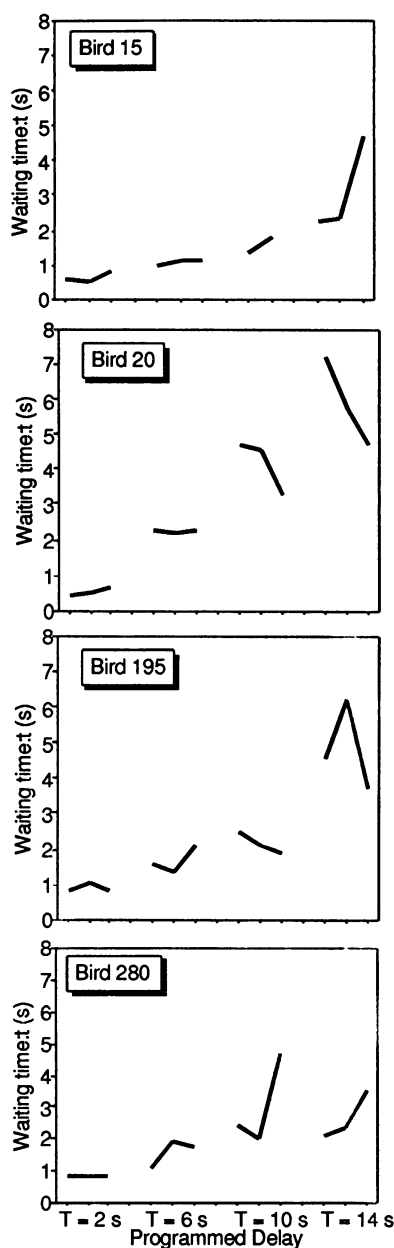


Fig. 2. Session median waiting times in Experiment 1 against programmed delay ( $T$ ), ordered according to  $T$  value and order of session. The first data point is thus the median of the waiting times for the first session at the shortest  $T$  value, the second point the median from the second session at the shortest  $T$  value, and so forth.

lated on the basis of the relationship between  $t$  and  $T$  and then reformulated in terms of  $I$  [if  $t = AI$  and  $I = T + t$ , then  $t = AT/(1 - A)$ ]. A regression of  $t$  directly onto  $I$  is not legitimate on a *fixed* RID schedule, because within-session variation in the interfood in-

terval is caused entirely by variation in  $t$ , and this forced covariation spuriously inflates the correlations. These regression lines through the origin fit the data well, with the exception of Bird 280.

The figure also shows the results from these same birds in comparable conditions in our previous study (Wynne & Staddon, 1988, Experiments 1 and 2, fixed conditions). The points for Birds 20 and 195 are within the 95% confidence lines of the present study, but Birds 15 and 280 show smaller  $A$  values in the present than in the earlier study. Linear regressions on the data points in these panels produced  $A$  values from the previous studies for Birds 15 and 280 of .21 and .29, respectively. In both cases the differences between these values and those obtained in the present study are statistically significant (Bird 15: Student's  $t = -4.04$ ,  $df = 6$ ,  $p < .01$ ; Bird 20:  $t = -4$ ,  $df = 6$ ,  $p < .01$ ). Thus, for these 2 birds, additional experience reduced the pause fraction; for the other 2, the additional experience had little effect.

Figure 2 shows for each bird the median waiting times for each session. These are first grouped in order of the programmed delays ( $T$  values), and within each delay value in their order of occurrence. The first point for each subject thus shows the session median  $t$  value for the first session at  $T = 2$  s, the second point is the median  $t$  value from the second session at  $T = 2$  s, and so on (of course, in the actual course of the experiment sessions at other  $T$  values usually intervened between those shown connected in this figure). The direct relation between waiting time and  $T$  is apparent even on the first session under each  $T$  value, and does not change in a uniform way on later exposures.

Other studies on similar RID schedules have produced  $A$  values similar to those reported here and in Wynne and Staddon (1988). Manabe (1990, Table 2) reported values of .18 to .35; Shull, Guilkey, and Brown (1978, estimated from Figure 2) reported an  $A$  value of .27. Shull (1970) found a larger  $A$  value: .56 (estimated from his Figure 1). In all these studies substantial numbers of consecutive sessions were presented at each parameter value. Most of these  $A$  values are somewhat shorter than the typical postreinforcement pause fraction in standard FI experiments (.5 to .7: Schneider, 1969; .45: Schneider & Neuringer, 1972), but the pause on FI schedules is typi-

cally derived from an estimated break point in the scalloped pattern of responding. Break points necessarily occur at longer postreinforcement times than the first response, which defines waiting time on RID schedules. Different methods of assessing pausing can produce estimates of  $A$  from the same data base that differ from each other by over 60% (Dukich & Lee, 1973; Richelle & Lejeune, 1980). Some data from FI schedules indicate that even when a given FI value is maintained across a long block of sessions, the pause fraction is in the same range as the values reported here (.17 to .19; Gentry, Weiss, & Laties, 1983, Table 1). Thus, there is no clear evidence that waiting time on daily varied short-IFI RID schedules is consistently shorter than under conditions in which schedule parameters are held constant for many sessions.

We conclude, therefore, that additional exposure to daily varied short-IFI RID schedules does not systematically improve temporal control. Also, under our conditions, the adjustment of waiting time to changes in schedule parameters is usually rapid, occurring well within the first session of exposure to each new parameter value. Finally, over the range of IFIs studied here, the pause fractions we find are within the range of those found in chronic studies. In the next experiment, we look more directly at changes in waiting time within and between sessions on daily intercalated fixed RID schedules.

## EXPERIMENT 2: INTERCALATED RID SCHEDULES: THE DEVELOPMENT OF TEMPORAL CONTROL

Experiment 1 showed that additional experience with a given schedule value, when values are changed daily, does not seem to produce systematic changes in temporal control. When, therefore, does temporal control develop under these conditions? In this experiment, we attempted to answer this question by looking more closely at the process of acquisition in pigeons with no previous experience on delay schedules.

### METHOD

#### Subjects

Four White Carneau pigeons with extensive histories on a variety of nontemporal discriminations and concurrent schedules were main-

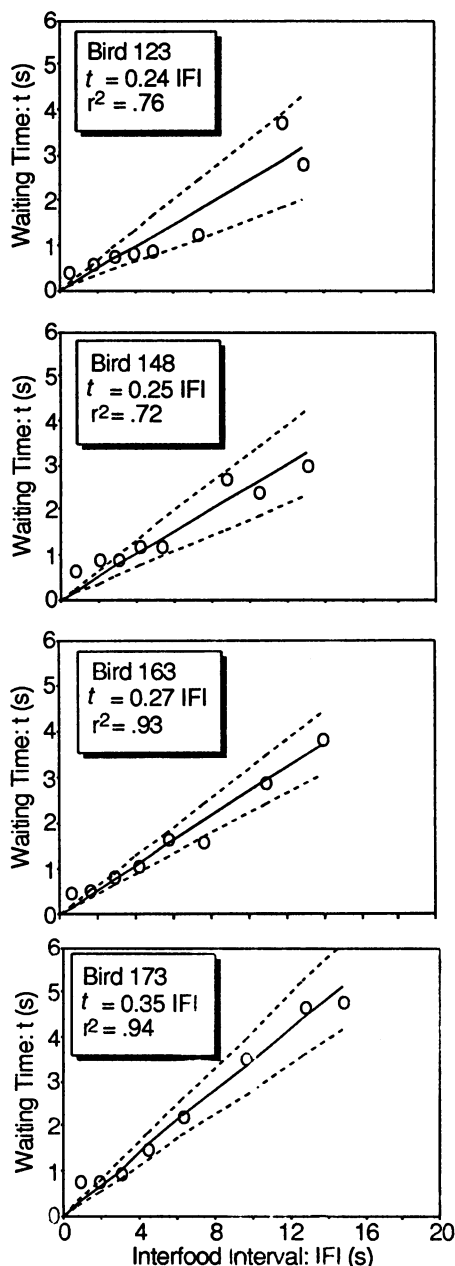


Fig. 3. Condition median waiting times against median interfood intervals for each bird in Experiment 2. Each panel includes the regression line through the origin with 95% confidence interval and the regression equation parameters.

tained at about 80% of their free-feeding weights.

#### Apparatus

The pigeons were studied in a standard cubic conditioning chamber (30 cm on a side) at

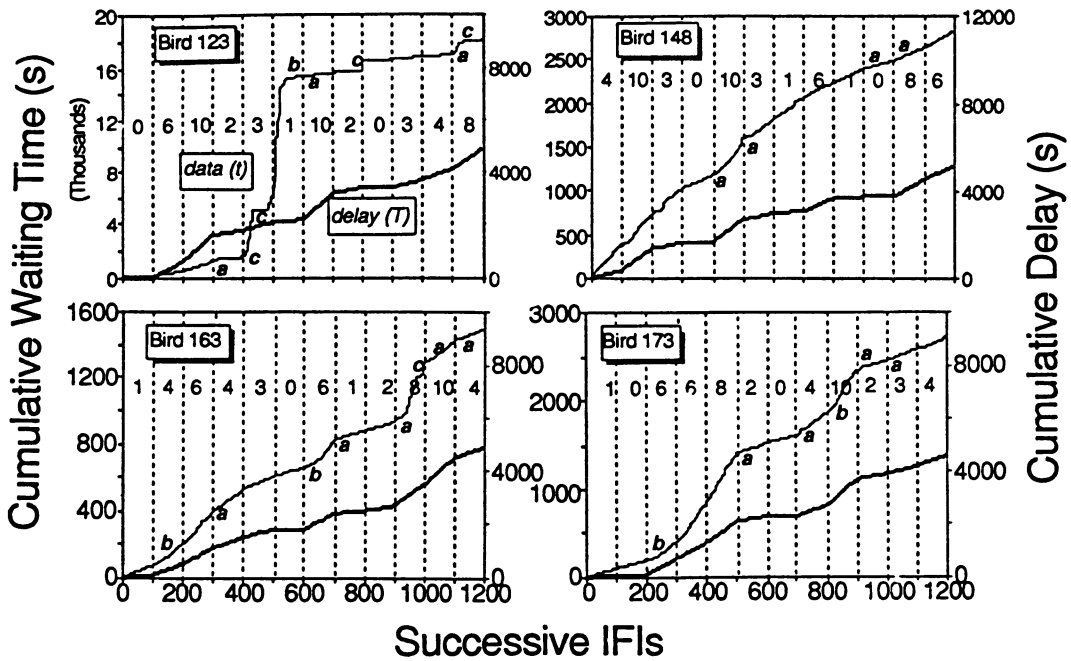


Fig. 4. Cumulative waiting times for each bird through the first 12 sessions of Experiment 2. Cumulated delays are also shown (heavy lower line in each panel), as are the session delay values. The cumulated delays have been arbitrarily scaled to fit in the lower half of each panel. Dashed vertical grid lines mark session boundaries. Lowercase letters (a, b, and c) identify different kinds of changes in the cumulative record; see text for further details.

Duke University. This operant chamber contained a single illuminable key, a houselight, a grain hopper with hopper light, and ventilation fan that also provided masking noise. The houselight was on throughout the experiment, and the hopper light was on during reinforcement. The experiment was controlled by a Commodore® microcomputer that also recorded the times of all experimental events. Data were transferred at the end of each session to a larger computer for analysis.

#### Procedure

The procedure was the same as in Experiment 1. Subjects received daily sessions consisting of one of eight  $T$  values (response–food delays): 0 (fixed-ratio 1 followed by a green flash with food), 1, 2, 3, 4, 6, 8, and 10 s, presented nine to 11 times each in random order.

#### RESULTS

Figure 3 shows the condition median waiting times as a function of interfood interval for each bird, presented with regression lines through the origin as in Figure 1. Data points

outside the 95% confidence intervals differ significantly from the linear trend. Waiting times at IFIs less than 4 s or so do not fall on the line but are approximately constant, suggesting a lower limit on waiting time of about 0.5 to 1 s, depending on the pigeon. Outside this range of IFIs, the relation between  $t$  and  $I$  is approximately linear through the origin, as before.

How does waiting time change as the imposed delay,  $T$ , changes? After exploring a number of possibilities, we settled on a form of cumulative record as the simplest method of displaying details of the acquisition process in an unbiased way (Figure 4). In these records the  $x$  axis shows successive IFIs, and the  $y$  axis shows cumulated  $t$  values in successive IFIs. Cumulated  $T$  values are also shown.

It is impossible to show the entire experiment in this way without losing all detail, but in Figure 4 we show the first 12 sessions for each pigeon (vertical grid lines indicate session boundaries). Each panel has two lines: The thicker and lower one represents cumulated delay value,  $T$  (right-hand  $y$  axis). Changes in the slope of this line give an indication of

changes in the independent variable from session to session; the numerical  $T$  values are also shown for each session. The thinner line is waiting time,  $t$ , cumulated IFI by IFI. Notice that in these records, increased slope means longer waiting times (i.e., the inverse of the usual response-based cumulative record). Thus, if the pigeons adapt to the daily changes in  $T$ , the slope changes in the cumulative  $t$  record should follow the changes in the cumulative  $T$  record.

The major features of the waiting-time curves are indicated by lowercase letters, as follows: (a) immediate, appropriate slope change at a session boundary (higher if  $T$  has increased, lower if  $T$  has decreased); (b) appropriate slope change delayed after session boundary; and (c) anomalous slope change (there are several kinds of these, such as mid-session changes in the wrong direction, large, inappropriate changes at the beginning of a session, etc.).

Most of the slope changes for most pigeons were rapid—within a single session—and appropriate (i.e., in the right direction; labeled a and b). Usually the changes were very rapid (i.e., after one or two IFIs; labeled a), but sometimes they were more gradual or delayed (though still within a single session; labeled b). One pigeon showed bouts of excessive pausing, often followed by periods of very short pauses (Bird 123, especially during the first  $T = 1$  s and  $T = 3$  s conditions and the second  $T = 0$  s session); many of these are labeled c. These very long and very short pauses were a persistent pattern for this pigeon. Otherwise, all birds showed very rapid adjustment to the prevailing  $T$  value.

The session median waiting times as a proportion of session median interfood interval (session  $A$  values) across sessions showed no systematic changes through the course of the experiment. There were some irregular slow changes in the pause fraction,  $A$ , across many sessions, but these changes were usually small (most  $A$  values lie between .15 and .35 for Birds 123, 148, and 163 and between .2 and .4 for Bird 173).

#### DISCUSSION

This experiment shows four things: (a) The typical linear relation between waiting time,  $t$ , and interfood interval,  $I$ , is easily replicated with pigeons untrained on delay procedures and tested with different, short (0 to 10 s)  $T$

values each day. (b) The linear relation seems to break down at very short  $T$  values ( $< 4$  s or so). This seems to reflect a lower limit on waiting time on the order of 1 s, probably the time it takes the bird to return to the key after feeding. (c) Pigeons adapt rapidly to each new  $T$  value, often within one or two IFIs, and nearly always within a single session. Thus, the experienced subjects in Experiment 1 did no better (indeed, they did nonsignificantly worse, with slightly smaller  $A$  values: Experiment 1,  $A = .20$ ; Experiment 2,  $A = .28$ ; Student's  $t = 2.19$ ,  $df = 6$ , not significant) than the naive subjects in Experiment 2. The results from Experiments 1 and 2 are in agreement: When parameters are varied daily, temporal control on short-IFI RID schedules is as good after a single session as it will ever be. (d) There are slow, session-by-session changes in the pause fraction,  $A$ , but these are small in magnitude and not systematic.

Thus, Experiments 1 and 2 together reinforce our earlier conclusion (Wynne & Staddon, 1988) that temporal control on daily varied RID schedules develops rapidly, at least when the times involved are relatively short.

#### EXPERIMENT 3: COMPARISON OF RID AND FI SCHEDULES

Manabe (1990) found shorter waiting times on a fixed- $T$  RID schedule than on an FI-like schedule, when conditions were presented in consecutive blocks. In this experiment we see whether a difference exists between an FI schedule and a fixed- $T$  RID schedule when schedule parameters change daily. This experiment tests whether the rapid temporal control we found in Experiments 1 and 2 and in the studies by Wynne and Staddon (1988) is possible on FI and, if so, whether it is similar on FI and RID schedules. Four naive pigeons were studied on a direct comparison between the fixed- $T$  RID schedule and comparable (i.e., similar IFI) FI schedules, in which the relevant schedule parameter changed daily.

#### METHOD

##### *Subjects*

Four homing pigeons of local stock, with some experience on visual discriminations, served as subjects at 80% of their free-feeding weights.

Table 1

Parameter values of linear regressions through the origin on Experiment 3 (Figure 5), and significance of differences between regressions in FI and RID conditions.

Bird	FI		RID		Difference		<i>p</i>
	<i>A</i>	<i>r</i> <sup>2</sup>	<i>A</i>	<i>r</i> <sup>2</sup>	<i>A</i> <sub>FI</sub> - <i>A</i> <sub>RID</sub>	<i>t</i>	
3	.28	.84	.31	.92	-.03	-1.29	NS
4	.30	.91	.31	.93	-.01	-0.53	NS
18	.27	.92	.29	.39	-.02	-0.75	NS
19	.22	.23	.15	.79	.07	3.74	<.05

### Apparatus

Subjects were studied in a cubic conditioning chamber at the University of Konstanz identical to that used for Experiment 1, with the addition of a blue keylight. A Commodore® 64 microcomputer with DELA interfacing (Wynne, 1990) controlled the experiment and recorded the times of each experimental event. Data were later transferred to a larger computer for analysis.

### Procedure

Two types of schedules were used, RID and FI. The RID schedule was the same as in Experiments 1 and 2. The pecking key was initially illuminated red; on the pigeon's first peck it turned green and remained green for a time, *T*, fixed each day by the experimental program, before grain was made available for 2 s. The next cycle followed immediately. Each daily session consisted of 100 identical cycles. In different sessions, four *T* values, 6, 10, 14, and 18 s, were presented. Under the FI condition the pecking key was continuously illuminated blue, except during reinforcement, when it was dark. The first response after *I* s had elapsed since the last reinforcement was reinforced with 2-s access to mixed grains. We studied FI (*I*) values of 8, 13, 18, and 23 s. The houselight was continuously illuminated throughout each session. Each parameter value for each schedule type was presented in approximately six daily sessions. Sessions of different schedule types and parameter values were intermixed pseudorandomly. No shaping or other pretraining was used.

### RESULTS

Figure 5 presents, for each pigeon, the condition median waiting time against IFI, together with the best fitting regression line through the origin for each schedule type. The

parameters of the lines are listed in Table 1. Included in this table are *t* tests for differences between the gradients (*A* values) of the regression lines under the two conditions. Only Bird 19 showed a significant difference in *A* values between the conditions, and this bird showed lower *A* values than the others under both conditions. For the other subjects, the data from the two conditions shown in Figure 5 are linear and do not differ in slope.

Figure 6 shows the development of pausing through the experiment. Session *A* values are plotted in the order in which the sessions took place (separately for the FI and RID conditions). The figure confirms that only for Bird 19 are there differences between *A* values under the two conditions. The figure also shows some increase in pausing as a proportion of IFI over the course of the experiment. Linear regressions of the *A* values against session number had gradients significantly greater than zero (*t* test, *p* < .05) for some birds and conditions: Bird 3 (both conditions), Bird 18 (RID), and Bird 19 (RID).

### DISCUSSION

This experiment shows that waiting time is proportional to IFI on both FI and fixed-*T* RID schedules, and that there is no significant difference in the pause fraction when parameter values are changed daily. The 1 pigeon for which a difference was found (Bird 19) also showed little linear waiting on either schedule. For the others, the *A* values on FI and RID with IFIs in the same range are indistinguishable.

We found some change in postreinforcement pausing as a proportion of IFI over the course of the experiment. This is largely due to very small *A* values at the start of the experiment (Figure 6). The previous experience of the birds in this experiment was with simple visual



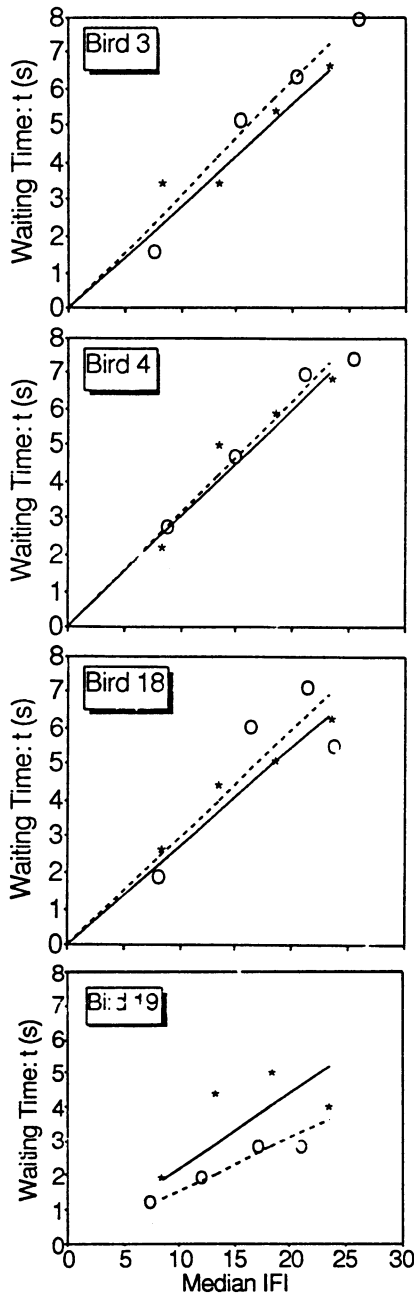


Fig. 5. Condition median waiting times against IFI for each bird in Experiment 3. Open circles and dotted line: RID conditions. Asterisks and solid line: FI conditions. Parameters of the through-the-origin regression lines are included in Table 1.

discriminations—procedures in which the typical IFI was very short. But the birds in Experiment 1 had extensive experimental histories with delay schedules and much longer IFIs.

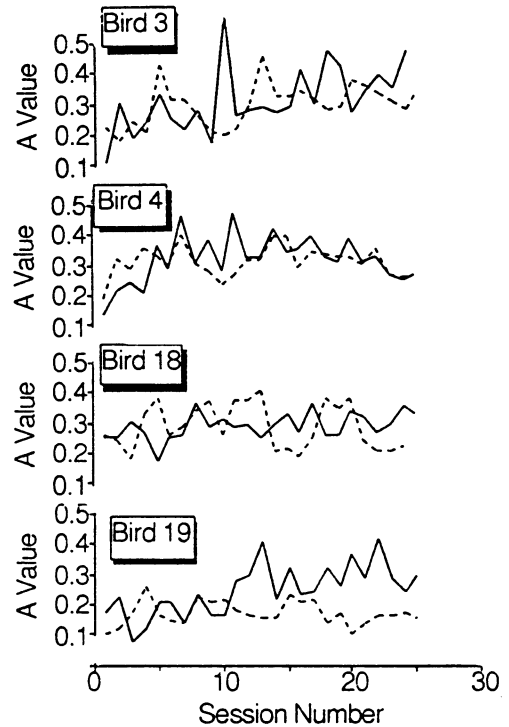


Fig. 6. Session *A* values in the order of occurrence of the sessions in Experiment 3. Dotted lines: RID conditions. Solid lines: FI conditions.

The experience with very short IFIs may be the reason for the short waiting times early in this experiment; they may therefore represent a sort of proactive interference. We take up the theme of proactive interference again later, in connection with the results of Experiments 4 and 5.

The pause fractions (*A* values) here (excluding Bird 19 which showed poor control), ranged from .27 to .31 (Table 1). The mean of the 16 *A* values in this and the previous two experiments was .25, with a standard deviation of .06. This means that we can say with 95% confidence that postreinforcement pauses more than 38% (or less than 12%) of IFI are evidence of a different process than that which we observed here. Thus, the pause fractions from many previous studies on RID schedules, even though obtained in blocks of sessions at one parameter value, are consistent with the temporal control we have found (e.g., Chung & Neuringer, 1967; Manabe, 1990; Shull et al., 1978). The results from studies on FI schedules, although difficult to compare because of the different methods of assessing postrein-

forcement pausing, appear to show longer pausing (e.g., Manabe, 1990; Schneider, 1969; Schneider & Neuringer, 1972), although at least one study reports smaller  $A$  values (Gentry et al., 1983).

The difference between an FI-like condition and an RID condition with fixed delay ( $T$ ) found by Manabe (1990), and the failures to find such a difference here and in Wynne and Staddon (1988, Experiment 4, clamped vs. fixed conditions), may be traceable to differences in the distributions of interfood intervals between the two schedule types; an hypothesis about this difference will be outlined below. But there is also a procedural difference that may contribute to the different results. Manabe programmed a timeout, during which the operant chamber was dark, to signal the food delay. In our studies, delays were signaled by a neutral stimulus (keylight), and in other studies (e.g., Chung & Neuringer, 1967; Shull, 1970), there was no stimulus change. A timeout is generally considered to be an aversive stimulus (e.g., Ferster, 1953; Thomas, 1965). For example, programming a timeout contingent on a fixed-ratio (FR) schedule leads to a reduction in the rate of FR responding (Kaufman & Baron, 1968). In Manabe's study, the birds could reduce the duration of the timeout by waiting longer only in the FI-like conditions (our clamped RID schedule), because the duration of  $T$  under those conditions is just  $I - t$ . But when  $T$  is constant (our fixed RID schedule), timeout duration is independent of waiting time. Thus, short waits may have been selectively punished in Manabe's FI-like condition, but not in his fixed RID condition. This selective punishing of short waiting times in the FI-like condition may have contributed to Manabe's finding that his pigeons waited longer on the FI-like schedule.

#### EXPERIMENT 4: DAILY INTERCALATED LONG DELAY VALUES

We have discussed three factors that might contribute to the rapid development of temporal control on periodic-food schedules: experience with periodic schedules, schedule type, and length of delay. Experiments 1, 2, and 3 showed that under conditions of daily parameter change, neither schedule type nor experience seems to be important. It remains pos-

sible that the short IFIs (typically  $<20$  s) used in these experiments may be essential to the rapid development of temporal control that is uniform (similar  $A$  values) across schedule types. When RID schedules with longer ( $>30$  s) IFIs are intercalated daily, does linear waiting develop in the same way as when short-FI schedules are intercalated? Here we test this possibility.

This experiment was designed similarly to Experiments 1 and 2: Fixed RID schedules with five different  $T$  values, this time ranging from 20 to 60 s, were intermixed daily. In order to have a baseline of behavior on short delays, and because Experiment 1 had shown (at least with short IFIs) that there is no effect of experience on temporal schedules per se (beyond the first few sessions, see Figure 6), we used the subjects from Experiment 2.

#### METHOD

##### *Subjects and Apparatus*

Subjects, apparatus, and feeding regimen were the same as in Experiment 2.

##### *Procedure*

We used the same fixed- $T$  RID schedule as before.  $T$  values of 20, 30, 40, 50, and 60 s were presented for 10 sessions each (nine sessions for  $T = 60$  for Bird 163) in pseudorandom order. Each session lasted for 100 cycles.

#### RESULTS

The crosses in Figure 7 show the individual relations between  $t$  and  $I$  in this experiment; asterisks indicate the comparable data from the shorter IFIs studied in Experiment 2. Visual inspection of the new data shows that a regression through the origin would be inappropriate; thus, the regression lines shown in the figure include intercepts. Tests of the regression gradients against zero (Student's  $t$ ) confirmed the visual impression that waiting times here did not increase with interfood interval. For Birds 148, 163, and 173, most of the waiting times were consistent with those that would be expected on the basis of linear waiting on the shortest delay presented ( $T = 20$  s). The waiting times for Bird 123 were consistently very short (under 2 s) and not obviously related to any of the IFIs in this experiment (this bird was always prone to erratic behavior; see Figure 4).

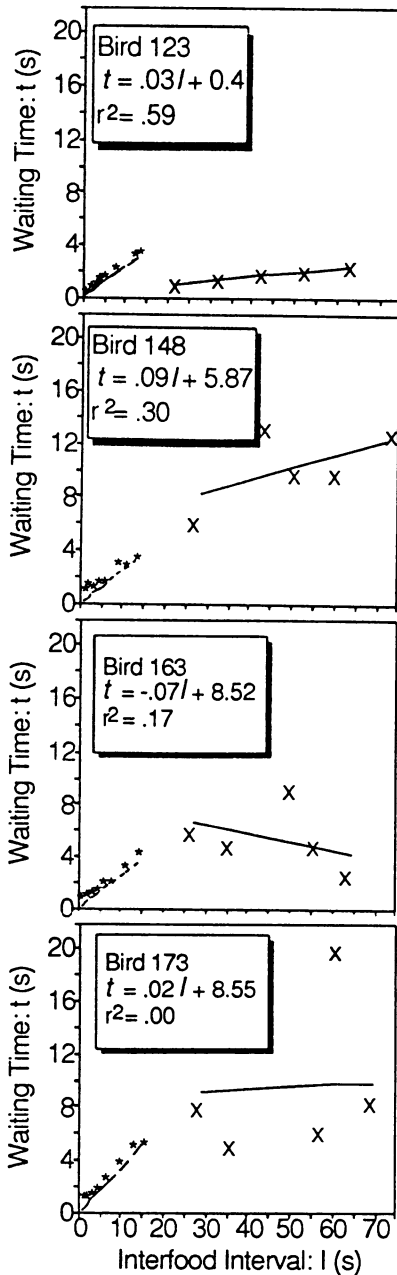


Fig. 7. Condition median waiting times against IFI for each bird in Experiment 4 (crosses). Each panel includes the line of best fit and the regression equation parameters. For comparison, condition medians are included from the same subjects in Experiment 2 (asterisks) with regression lines through the origin.

The average data in Figure 7 do not tell the whole story, however. Figure 8 shows the pause fraction (*A* value) session by session for each bird throughout the experiment. There is a

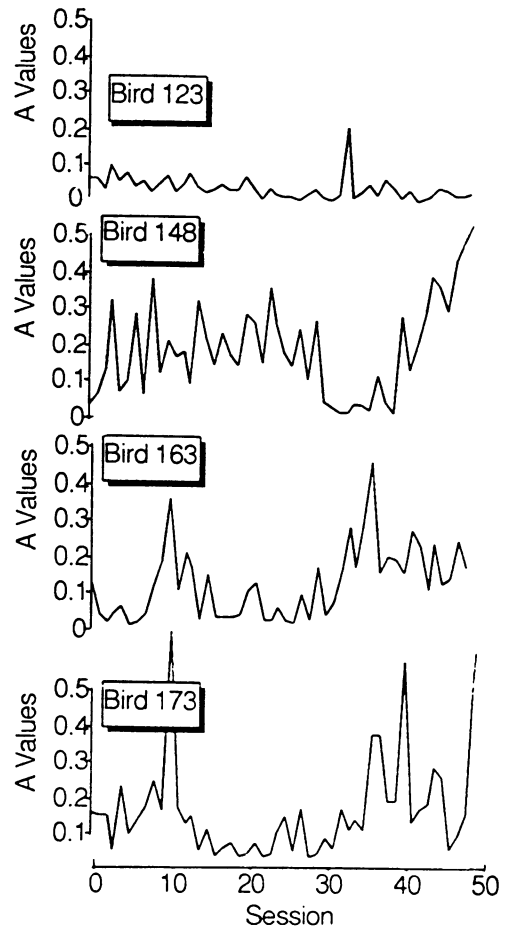


Fig. 8. Session *A* values in the order of occurrence of sessions in Experiment 4.

difference between these results and those obtained with short-IFI schedules in Experiment 2. *A* values here systematically increased for Bird 148 and Bird 163, and possibly also for Bird 173 (Bird 123 had failed to show any temporal control throughout the experiment). This impression is confirmed in the cumulative *t* plots in Figure 9, which shows cumulative *t* values from the first and last six sessions for 3 of the 4 pigeons (Bird 123 is omitted because its data show nothing of interest). In the later sessions, all 3 birds showed some changes in waiting time more or less appropriate to the prevailing *T* value (the very long waits in the last condition for Bird 173 make the relation harder to see for this bird). But the pattern is strikingly different from the rapid "appropriate" shifts when IFIs are short (a and b in Figure 4).

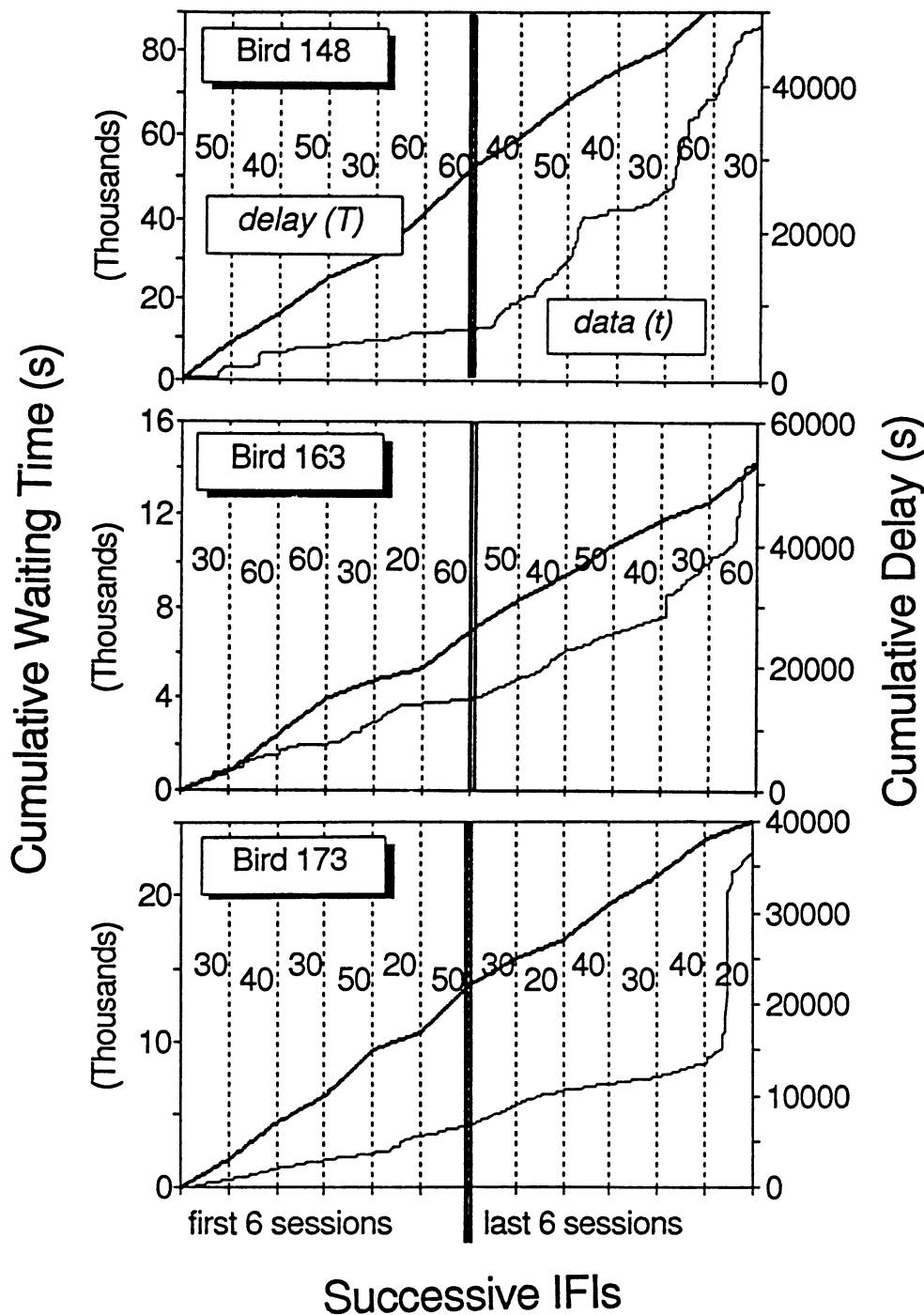


Fig. 9. Cumulative waiting times for Birds 148, 163, and 173 through the first six and last six sessions of Experiment 4. Cumulated delays are also shown (heavy upper line in each panel), as are the session delay values. The cumulated delays have been scaled to fit in each panel. Vertical grid lines mark the end of each session. A double grid line in the center of each panel separates the first six from the last six sessions.

## DISCUSSION

The rapid linear-waiting adjustment to daily varied short ( $<20$  s)  $T$  values that we saw in Experiments 1, 2, and 3 was not found in this experiment with  $T$  values in the 20- to 60-s range. Although some of the birds after many sessions began to show longer pauses, the cumulative  $t$  records rarely showed the rapid, appropriate adjustment to daily changes in  $T$  value that we found in the earlier experiments. Moreover, the pattern of the records in this experiment is clearly more variable than in the earlier experiments with short IFIs.

What are we to make of these differences? There are two obvious possibilities. There may be an intrinsic difference between long and short IFIs. Perhaps because of memory constraints, pigeons may be unable to adapt easily to long IFIs, as they can when the prevailing IFI is shorter. The second possibility is that the poor temporal control in this experiment is not a property of long IFIs per se, but reflects proactive interference from these pigeons' prior experience with short IFIs. Perhaps the cumulative  $t$  records here are variable because of residual "intrusions" from the subjects' earlier experience with short IFIs: There may still be some tendency to respond at short postfood times, just because all the birds had experienced many sessions with short IFIs. (Proactive interference, as mentioned above, could also account for the initially very short waiting times shown by the birds in Experiment 3; these birds had prior experience in experiments with very short interfood intervals.)

The data here do not distinguish easily between these two possibilities. The cumulative records themselves tend to favor the first option (that there is an intrinsic difference between long and short IFIs) because even the "best" bird, Bird 148, which was clearly beginning to approximate linear waiting towards the end of this experiment, nevertheless shows cumulative  $t$  records that look very different from its data under short IFIs. These records are much more variable, and much less tightly tied to the prevailing  $T$  value, than the short-IFI records in Figure 4.

#### EXPERIMENT 5: BLOCKED LONG DELAY VALUES

Experiment 4 showed that when food delays longer than 20 s were intercalated daily, waiting time ceased to be proportional to the pre-

vailing interfood interval. Here we attempt to distinguish two possible reasons for this breakdown in linear waiting. If longer interfood intervals intrinsically gain control more slowly (are more difficult to learn), then the development of waiting time when any longer delay value is presented in a block of identical sessions should depend only on the length of the prevailing interfood interval, and be independent of the subject's prior experience. If, on the other hand, longer interfood intervals are less able to control waiting time because of proactive interference from previous shorter interfood intervals, then the rate of adaptation to an interfood interval should depend on the subject's history. If the pigeon's previous experience is with shorter interfood intervals, temporal control should take longer to develop than when the pigeon has prior experience with longer interfood intervals (a tendency to respond too early will preempt a tendency to respond later, but not vice versa). In this experiment subjects were exposed to each delay value for many consecutive sessions (until the waiting times in successive sessions fulfilled a stability criterion). In alternate conditions the delay to food was 40 s. In the other conditions the food delay could be 20 or 80 s. According to the proactive interference hypothesis, the pigeons' pausing should stabilize more rapidly on the  $T = 40$  s condition when it follows a  $T = 80$  s condition than when it follows a  $T = 20$  s condition. If the longer interfood intervals are intrinsically more difficult to learn, then responding on the  $T = 40$  s condition should not be affected by which condition ( $T = 20$  or 80 s) preceded it, but the number of sessions before pausing stabilizes should be proportional to the experienced IFI.

## METHOD

*Subjects*

The 4 homing pigeons from Experiment 3, still held at 80% of their free-feeding weights, started the experiment. Bird 3 became sick and was removed from the study; its results are not presented here.

*Apparatus*

Subjects were studied in the apparatus used in Experiment 3, without the blue keylight.

*Procedure*

The birds were exposed to the same RID schedule as in Experiments 1 through 4. Each

Table 2

Session parameters and number of sessions at each parameter value in Experiment 5.

Bird	<i>T</i>	Total number of sessions	Sessions to stability	Mean wait
4	20	23	13	6.7
	40	51	18	14.4
	80	53	41	25.7
	40	16	9	18.3
	20	52	46	6.7
	40	52	3	11.0
18	40	44	17	11.9
	20	50	32	6.7
	40	42	23	20.9
	80	51	28	22.1
	40	53	7	11.7
19	80	51	39	25.8
	40	48	22	25.4
	20	50	25	13.5
	40	63	26	18.5
	80	22	3	33.8
	40	14	11	17.9

daily session consisted of 50 identical cycles, each of which terminated with 2-s access to mixed grains. Because the birds had prior experience, no shaping or pretraining was utilized. One of three *T* values (20, 40, and 80 s) was presented in consecutive sessions until the birds' waiting times were deemed stable. Stability was determined by one of two methods. For the first 50 sessions a linear regression was calculated by the method of least squares on the median waiting times over the last 12 sessions. The subject progressed to the next condition if the gradient of the session-median waiting-time regression was significantly likely ( $p > .95$ , *t* test) to be zero. After the first 50 sessions, the birds proceeded to the next condition when the session-median waiting times appeared stable by visual inspection. The sequence of *T* values was determined as described in the Introduction, and is shown in Table 2.

## RESULTS

Daily changes in the session-median waiting times are shown for each bird in Figure 10. The session-median values are shown as points; the solid line is the moving average of groups of five session medians (values were not averaged over condition boundaries). Horizontal lines are the means of the session-median waiting times over the last 10 sessions of

each condition (values are given in Table 2). After consideration of a number of possibilities, we settled on a rule of thumb to estimate the point at which behavior had become stable under each condition: Our estimate is the session at which the moving average line in Figure 10 crosses the horizontal line (i.e., the point at which the moving average of the session waiting times first reached the value that it had in the last 10 sessions of a condition). More elaborate statistical estimates are stymied by the dependency of the standard deviation of timing estimates on their mean (Weber's law in temporal data; Gibbon, 1977).

Figure 10 shows different patterns for the 3 birds. Waiting times for Bird 4 showed some rapid adjustment in the direction of the change in food delay on initial exposure to a new condition, but this initial rapid adaptation was never complete, and further gradual change in the same direction can be observed through the course of a condition. This subject showed little evidence of faster adaptation through the course of the experiment, and rarely do the waiting times overshoot the value calculated from the last 10 sessions of each condition. This bird's behavior became stable more rapidly on the *T* = 40 s condition that followed a *T* = 80 s condition than on the two occasions when a *T* = 40 s was preceded by a *T* = 20 s condition.

Bird 18 showed a similar pattern of gradual adjustment to each new schedule value under some conditions (the first three conditions), but also showed substantial overshooting of the terminal waiting-time value under two conditions (the second exposure to *T* = 40 s, and the *T* = 80 s condition). All three exposures to the *T* = 40 s condition were studied for approximately equal numbers of sessions, but pausing became stable more rapidly when the *T* = 40 s condition followed a *T* = 80 s condition.

Bird 19 showed a very different pattern of adaptation to the schedule conditions. Early exposure to each condition resulted in a substantial overshoot in the waiting times above or below the terminal value, which was then gradually "corrected" by changes in waiting time that brought this value back to the level it had on the previous condition (cf. the first *T* = 80 s condition with the first *T* = 40 s condition). For this bird, adaptation to the final *T* = 40 s condition (which followed a *T* = 80 s condition) was more rapid than adaptation to the previous *T* = 40 s (which followed

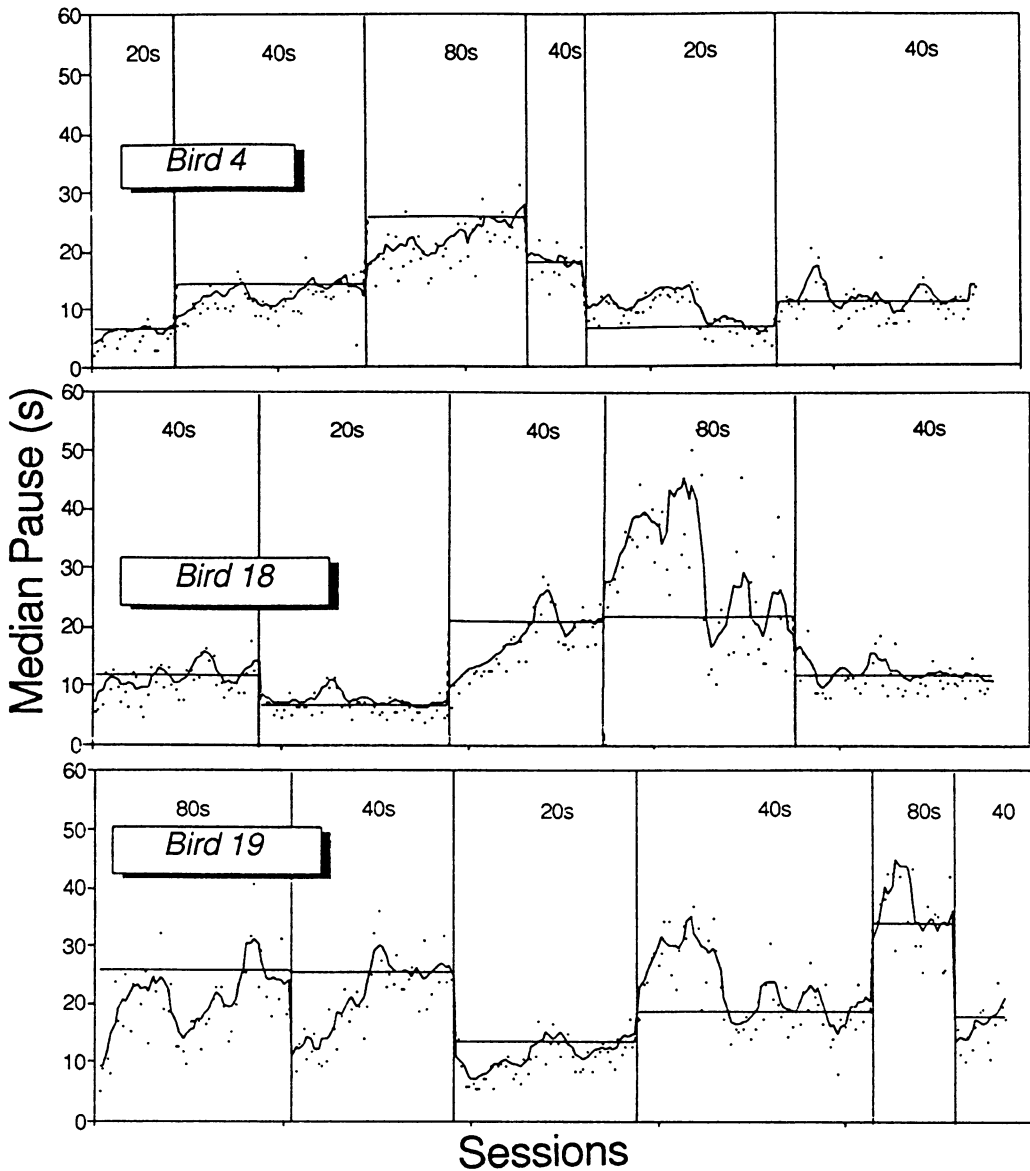


Fig. 10. Session median waiting times through the course of Experiment 5 for 3 birds. Scattered dots are individual session medians. Solid line shows the moving average of five sessions of session median waiting times through the course of the experiment. Horizontal lines show mean waiting time over the last 10 sessions of each condition. The prevailing  $T$  value is shown for each condition.

a  $T = 20$  s condition), but in the first  $T = 40$  s (which was also preceded by a  $T = 80$  s condition) many more sessions were required before the waiting times stabilized.

For none of the birds did the total number of sessions conducted, or the number of sessions to stable responding, correlate with the interfood interval.

Figure 11 shows the mean waiting times over the last 10 sessions of each condition

against mean obtained interfood interval for each bird. The relation between pause and interfood interval is linear, with intercepts close to zero, and gradients (pause fraction,  $A$ ) around .23 (the values for individual birds are inserts to the figure). Data points are condition sequence numbers to show possible order effects: No consistent effect of order on the mean waiting time is visible here.

Figure 12 presents an analysis of transitions

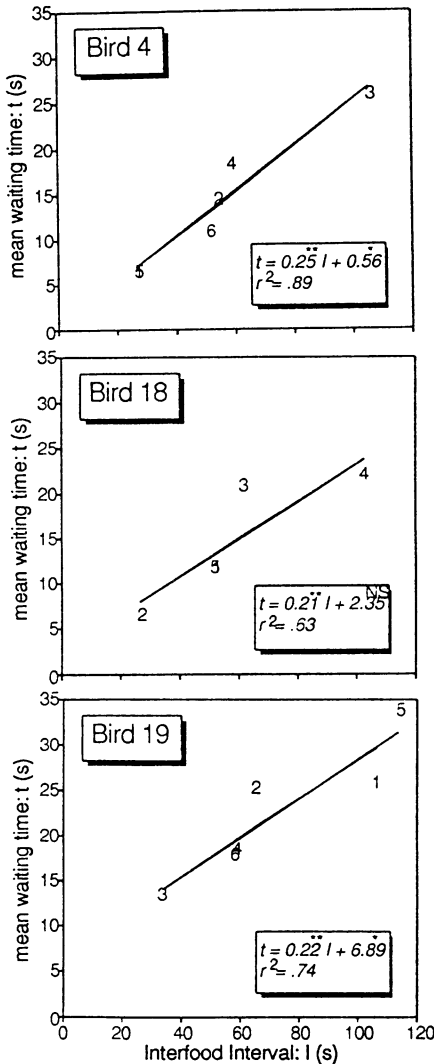


Fig. 11. Condition median waiting times over the last 10 sessions of each condition against IFI for 3 birds in Experiment 5. Each panel includes the line of best fit and regression equation parameters.

from one condition to the next. Here we calculated the absolute change in waiting time from the last three sessions of one condition to the first three sessions of the immediately following condition, and plotted the magnitude of this change against the change in food delay between the two conditions. The changes in mean waiting time when  $T$  decreased were, in fact, always negative, but presenting all the changes in positive space simplifies comparison of the magnitudes. It is clear that for all 3 birds waiting times changed more when food delay decreased than when it increased (with

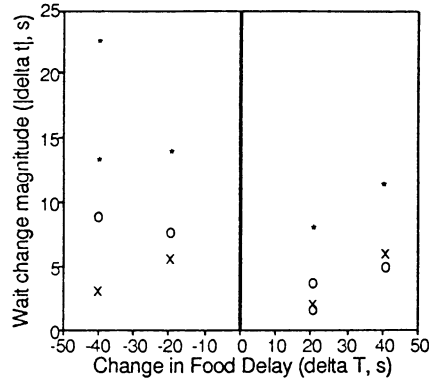


Fig. 12. Magnitude of the change in mean waiting time over the last three sessions of each condition and the first three sessions of the next condition ( $|\Delta t| = |\bar{t}_N - \bar{t}_{N-1}|$ , where  $\bar{t}_N$  is the mean waiting time in Condition  $N$ ), plotted against the change in programmed food delay ( $\Delta T = T_N - T_{N-1}$ , where  $T_N$  is the food delay programmed in Condition  $N$ ) for each bird in Experiment 5. Open circles: Bird 4. Crosses: Bird 18. Asterisks: Bird 19.

the exception of one point at  $\Delta T = 40$  s for Bird 18).

### DISCUSSION

These results permit three conclusions: (a) When RID schedules with interfood intervals longer than 30 s are presented in daily blocks, proportionality between waiting time and IFI develops—but takes several sessions, rather than occurring within a single session as it does when IFIs are shorter. (b) In the steady state, the pause as a proportion of IFI is similar to that found with the same birds in Experiment 3 with shorter IFIs changed daily ( $A \approx .23$ , zero intercept). (c) Waiting times tended to change more rapidly in response to a decrease in IFI than to an increase.

The steady-state pausing observed here is similar to that obtained from the same subjects on intercalated short-delay RID and FI schedules (Experiment 3, see Table 1). The pause fraction, intercept (with the exception of Bird 19, which here has a slight positive intercept), and proportions of variance accounted for by the regression equations are all very similar. Despite the comparability of the steady-state behavior, the dynamics of the waiting process here are very different than when shorter IFIs were used. The slow and very irregular between-session changes in waiting time in Figure 10 contrast with the rapid within-session adaptation found in Experiments 1 through 3.

It was not possible in this experiment to



demonstrate a dependency between the number of sessions required before waiting times appear stable and the magnitude of the prevailing interfood interval (although a comparison of Experiments 4 and 5 with Experiments 1 through 3 clearly demonstrates such an effect). However, as shown in Figure 12, waiting times adapted more rapidly to the prevailing IFI when the previous condition had consisted of longer IFIs than when the IFIs in the previous condition had been shorter. These results are thus consistent with our conjecture that adaptation to longer IFIs is slower because of proactive interference from earlier, shorter IFIs.

## GENERAL DISCUSSION

These experiments confirm our earlier report (Wynne & Staddon, 1988) that when typical interfood intervals are short (less than 20 to 30 s) and the schedule parameter value is changed daily, the time to first response (waiting time) is a linear function of the interfood interval, even when the type of schedule (fixed RID vs. FI) also changes from day to day. Experiments 4 and 5 confirm the impression gained from earlier studies that when interfood intervals are longer than 30 s or so, many consecutive sessions of training are required before waiting times become proportional to interfood interval. However, the steady-state pattern of waiting obtained at longer IFIs in Experiment 5 is very similar to that found with shorter IFIs.

Manabe (1990), studying pigeons for many sessions at each parameter value, found consistently longer pause fractions under a schedule equivalent to our fixed RID schedule (chain FR 1 FT) compared to an FI-like schedule. How can this difference be reconciled with our failure to find any difference in pause fraction when parameters are varied daily? We have pointed out a procedural difference (Manabe's use of a blackout rather than a key-stimulus change as the delay signal) that might be a factor. But there is another possibility suggested by the results of Experiments 4 and 5 and the many other studies (e.g., Catania & Reynolds, 1968; Ferster & Skinner, 1957) that have found that many consecutive sessions are required to obtain stable postreinforcement pausing on temporal schedules with interfood intervals longer than 30 s.

These results, and the cumulative waiting-time records we show for Experiment 2 (short IFIs) and Experiment 4 (long IFIs), suggest the possibility that the effectiveness of a given IFI as a determinant of subsequent waiting time depends on its absolute duration: Short IFIs are much more effective than long ones are. We are not sure how best to model this effect. But to fix ideas we will discuss a specific descriptive model, without claiming any uniqueness for it.

Suppose that the actual pause in any interfood interval is determined by a weighted average of all the IFIs the subject has experienced to that point, each devalued by a decay factor. Formally, this idea can be expressed as follows:

$$t_{N+1} = A(I_N, 0)I_N + A(I_{N-1}, 1)I_{N-1} \\ + \dots + A(I_{N-M}, M)I_{N-M} + \dots,$$

where  $t_{N+1}$  is the waiting time in cycle  $N + 1$  and  $I_N$  is the preceding interfood interval. The weights,  $A(I_{N-M}, M)$ , are functions of both age (how long ago the IFI occurred, approximately indexed by  $M$ ) and the absolute value of each IFI ( $I_{N-M}$ ). We assume that (a) older IFIs have less effect (weight  $A$  decreases as  $M$  increases), and (b) shorter IFIs have effects that decay more slowly (weight  $A$  declines more slowly for shorter IFIs) (a function with these properties is  $A[I_{N-M}, M] = kM^{-l}$ , where  $k$  is a constant). Notice that this model reduces to linear waiting if terms after the first are negligible or sum to a constant. The implications of this idea are not all obvious, so we will go through some examples showing how it applies to existing data.

Wynne and Staddon (1988, Experiment 3) showed that if delay is programmed to be proportional to the preceding waiting time, successive waiting times either increase or decrease, depending on the constant of proportionality. This effect implies some dependency of waiting time on the just-preceding IFI, although some effect of earlier IFIs is not precluded. In the simplest case, suppose that waiting time is half the immediately preceding IFI (i.e.,  $t_{N+1} = I_N/2$ ), but the schedule requires that delay time be four times the preceding wait ( $T_N = 4t_N$ ); then successive waiting times,  $t$ , should increase without limit. But in practice there is a limit: Although waiting times typically increased under conditions like this in our earlier study, the subjects rarely ceased to respond entirely. This limit to the positive-

feedback effect is consistent with Equation 2. So long as the IFIs are relatively short, the multiplier  $A(I_N, 0)$  will be large so that the previous IFI will have a dominating effect. But as IFIs get longer and longer, the effect of the preceding IFI diminishes relative to earlier, shorter (hence slower decaying) IFIs, and shorter waiting times reemerge.

This model also has implications for several topics raised by the present experiments: the difference between FI and fixed RID schedules, the different effects of changing parameters daily versus less frequently, and the difference between long and short interfood intervals. The critical issue is the nature of the set of IFIs to which the subject is exposed. This set defines the "window" within which an IFI can affect waiting time. The length of this window is uncertain at present. Based on the results of Experiments 4 and 5, we guess that for long IFIs the window may be up to 30 or more sessions. The window is long for long IFIs because their effects decline over time relative to the effects of short IFIs. Hence, a long IFI needs to be widely separated from any prior period of short IFIs if it is to have a detectable effect on waiting time. But because short IFIs have persistent effects, they need not be insulated from earlier periods with long IFIs; hence, the effective window for short IFIs may be just a few IFIs.

One implication of this analysis is that if the set of IFIs contains only short values, linear waiting should hold no matter how often IFI duration is varied. Thus, FI and fixed RID schedules with similar average IFIs will produce similar average pauses. But if the window contains long IFIs, then it needs to be long enough to isolate each long IFI from earlier short IFIs if the linear waiting relation is to hold. This doesn't mean that there cannot be one- or two-back effects within a set of long IFIs (Higa et al., 1991, and Innis & Staddon, 1971, have both shown tracking on cyclic schedules with IFIs in the range of 30 to 90 s). But it does mean that linear waiting is unlikely to be observed with a set of long IFIs soon after exposure to a period of short IFIs (cf. Experiment 4). It follows from this argument that linear waiting will not be observed when long and short IFIs are mixed on a daily basis, no matter how long training is continued (variable-interval schedules are an example of this).

Why should short IFIs be more persistent in their effects than long? There are at least two possible reasons, one intrinsic to the process of telling time, the other less well defined. First, even a weak tendency to terminate waiting (i.e., to respond) at short postfood times can preempt a much stronger tendency to respond at longer postfood times. Consider a subject that has been exposed to several sessions of short IFIs, say 20 s, and as a result has a strong tendency to begin responding about 5 s after food. Suppose that in the next session the prevailing IFI is 40 s. Based on its previous experience, the subject waits 5 s after the initial food delivery that begins the session. How long will it wait in the next IFI? The subject now has a strong tendency to respond at the 10-s postfood time, based on the previous IFI; but there is also a relatively strong, though weakening, tendency to respond at the 5-s point, based on a history of many sessions with a 20-s IFI. Under these conditions, it is obvious that the actual pause will tend to be determined by the shorter IFI, simply because the tendency to respond at the 5-s point will still be above threshold. Eventually, of course, the tendency to respond at the 5-s postfood point will fall below threshold, and 10-s pauses can then emerge. But initially, at least, any experience with short IFIs will tend to persist and cause short waits even when conditions have changed and the prevailing IFI is longer. And this effect is fundamentally asymmetrical: There is no comparable tendency for early experience with long IFIs to interfere with control by short IFIs. Notice in the cumulative  $t$  records in Figure 4 how the downshifts in IFI tend to produce more rapid and dramatic shifts in waiting time than the upshifts. The same effect is visible in Figure 12, where larger changes in waiting time are produced by decreases than by increases in  $T$ . Higa et al. (1991) have demonstrated this effect directly by interpolating occasional short (5 s) IFIs in a sequence of longer (15 s) IFIs: Waiting time is reduced only in the IFI following the 5-s "impulse."

Notice that the preemption effect by itself explains the difference between average waiting time on long FI and fixed RID schedules equated for mean IFI and presented in blocks of sessions. If short IFIs have a preemptive effect, then the fact that the shortest IFI on the RID schedule is much shorter than the fixed IFI on the FI schedule implies generally

shorter waits on the RID schedule. The argument implies that this difference should be much less when typical IFIs are short, however. Examination of Manabe's (1990) Figure 4 shows that indeed the pause fractions seem to differ less at short IFIs than at long ones, but an explicit comparison is needed.

The simple preemption argument does not explain the limitation of runaway pausing on Wynne and Staddon's (1988) autocatalytic schedule, because the preemption effect should block the run at its beginning rather than later. The model represented by Equation 2 can account for this effect, however, because the effect of a past IFI on waiting in the current IFI is jointly determined by its age (how long ago it occurred) as well as its length. In the autocatalytic procedure, the age factor always favors the previous IFI, but as postfood time increases, the balance can shift in favor of shorter, but older, IFIs because their effects decay more slowly.

The preemption argument does explain why the pause fraction on daily varied long-IFI schedules in Experiment 4 was so small, because those subjects had all received much prior experience with short IFIs. Moreover, the eventual apparent recovery of 2 or 3 of the pigeons (see Figure 9) after many sessions on long IFIs strongly suggests recovery from the proactive interference caused by the pigeons' earlier history with short IFIs; this is consistent with the idea that although the effects of short IFIs decay more slowly than long, they do eventually decay.

Is this preemption effect (of long waits by short) the only difference between long and short IFIs? Is this the only reason why short IFIs seem to be more persistent in their effects? Our guess is probably not, because even as Bird 148 (for example) showed signs of recovering temporal control under the long-IFI regimen in Experiment 4, its cumulative  $t$  record (Figure 9) nevertheless continued to look very different from the relatively unvarying but responsive-to-IFI-value records under the short-IFI regimen in Experiment 2 (Figure 4). And preemption by itself does not explain the apparently self-limiting positive feedback in the results of Wynne and Staddon (1988, Experiment 3).

Nevertheless, it would be interesting to test directly the prediction that short and long IFIs are fundamentally different. One way to do

this would be to use a modification of the method of Higa et al. (1991), just described. If longer IFIs are indeed different from short ones (other than being subject to the preemption effect), then this experiment should come out differently if the IFIs are scaled up (by a factor of six, say, to 30 and 90 s, respectively). The present hypothesis suggests that with longer IFIs, any effects of the occasional shorter IFI are not likely to be confined just to the following interval. Until experiments of this sort are done, however, we are left with the conclusion that the waiting behavior of pigeons on temporal schedules is determined differently at long and short postfood times, although the exact nature of this difference is not yet understood.

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